MODULE 10
SOUNDING ANALYSIS

OBJECTIVES

At the completion of this module, the student will be able to:

1) Understand how vertical profiles of temperature, humidity and pressure are obtained
2) Identify the five basic sets of lines on a sounding diagram
3) Understand how severe thunderstorm forecasters assess the potential for thunderstorm development based on a set of derived parameters
4) Compute the lifted index

SOUNDING PROCEDURE

The vertical distribution of temperature, pressure and humidity up to an altitude of about 98,000 feet (30 km) can be obtained with an instrument called a **radiosonde** (see Figure 10-1). The radiosonde consists of a small lightweight box equipped with special instrumentation that is attached to a gas-filled balloon. The balloons, which ascend through the atmosphere at a constant rate, are launched twice daily from approximately 60 locations across the country.

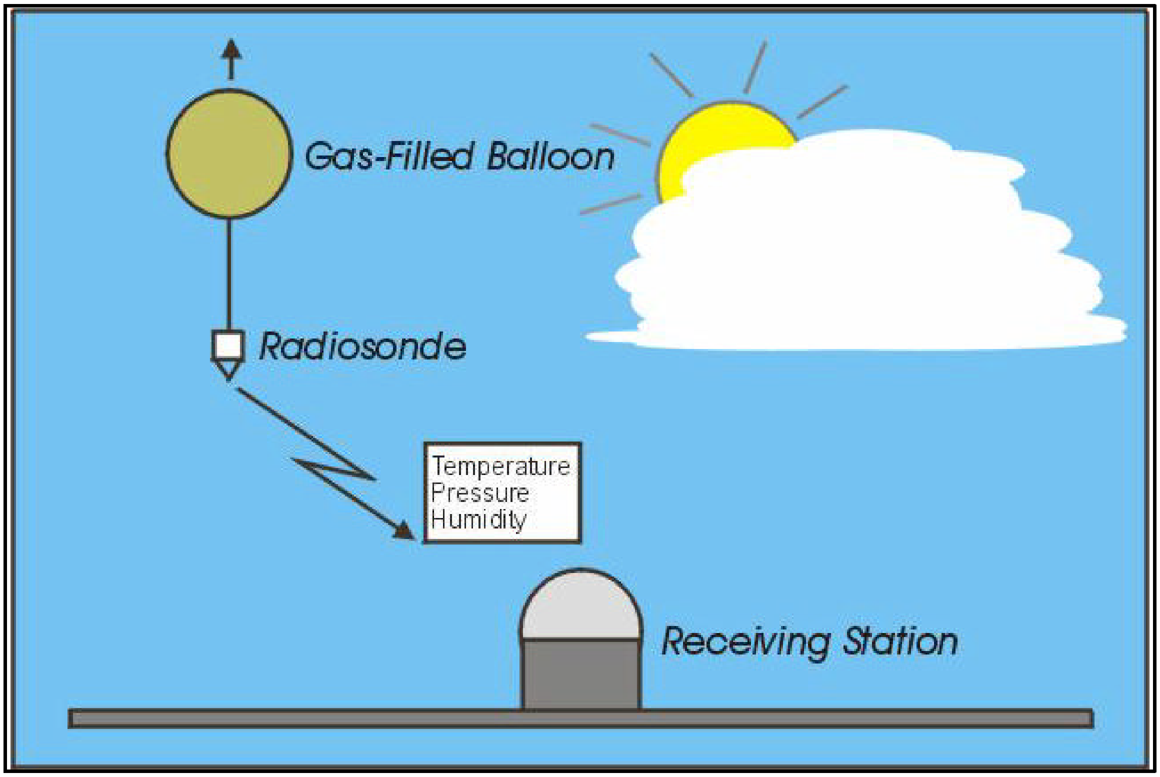

Figure 10-1: A simple schematic of the radiosonde. The radiosonde (the small instrument package being carried aloft by the balloon) sends readings of moisture, humidity and pressure via radio signals to a ground receiving station.

The instrumentation includes an electrical thermometer (thermistor) to measure temperature, a carbon-coated plate to measure humidity, and a small aneroid barometer to measure pressure. The box also contains a small transmitting radio to send signals (using a radio direction finder) of the measured elements back to a receiving station at the ground. These signals cannot easily be read in their raw electrical frequency form and must be converted. A computer performs the conversion into actual values of temperature, humidity and pressure as a function of height.

Tracking equipment at the ground receiving station can also follow the trajectory of the balloon in the horizontal direction as it rises at its constant rate in the vertical. Through simple geometry using elevation and direction angles, wind can be computed at various heights.

The resulting profile of temperature, humidity, pressure, and wind comprises what is known as a **sounding**. These soundings are very important to the severe thunderstorm forecaster, since they tell him/her a great deal about the extent of the moisture in the vertical and the amount of atmospheric instability above a station. As noted severe weather meteorologist Dr. Charles Doswell stated, “nothing can or should replace an examination of the individual soundings”.

SOUNDING DIAGRAM

The sounding that results from the vertical journey of the balloon and its radiosonde might look something like Figure 10-2. Wind has been left off of the diagram. The heavy lines represent temperature (on the right) and dew point (on the left). The forecaster plots this profile on what is called a **sounding diagram**. This diagram has a number of lines on it and can be quite confusing to the untrained eye.

For our purposes and in the interest of keeping things simple, just be aware that there are five basic sets of lines that forecasters use in analyzing a sounding. The horizontal solid lines represent pressure in units known as **millibars** (e.g. 500 mb). The solid lines that slant from the lower right corner of the diagram to the upper left are referred to as **dry adiabats**. They are lines used for comparing the actual sounding temperature at various heights to known temperature changes that unsaturated parcels of air experience as they move up or down in the atmosphere (remember our discussion on stability).

The third set of important lines represent **mixing ratio**. They are the right-slanted dashed lines in the figure. They provide the forecaster with a means of comparing the dew points in the actual sounding with known changes in moisture experienced by air parcels.

When a parcel becomes saturated, the fourth set of lines become important. They are the **saturation adiabats**. They are the curved dash-dotted lines. Saturation adiabats perform the same function as dry adiabats, but for saturated parcels.

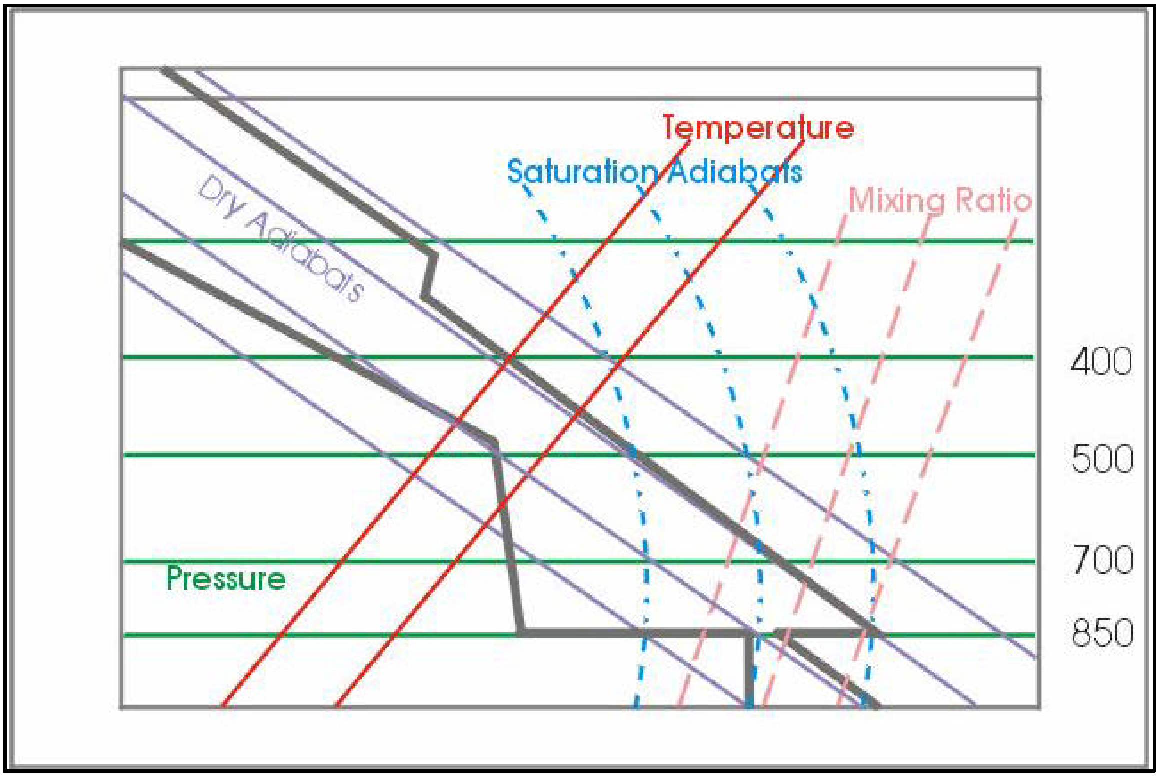

Figure 10-2: The sounding diagram. Heavy solid lines represent dry bulb (on the right) and dew point (on the left) temperature. The other lines are labeled. Pressure is in units of millibars (mb).

For reference, parcels following the dry adiabats decrease in temperature at a rate of 5.5 degrees Fahrenheit (F) per 1000 feet (1 degree Celsius per 100 meters). This is the dry adiabatic lapse rate discussed in an earlier module. Conversely, the saturated adiabatic lapse rate is less, or 3 degrees F per 1000 feet (0.5 degrees Celsius per 100 meters). We can compare these rates to the average decrease (or lapse) in temperature that is known to occur in the atmosphere: 3.5 degrees F per 1000 feet (0.6 degrees Celsius per 100 m).

The fifth and final set of lines, and perhaps the most important, are the **temperature** lines. In the diagram, these lines extend from the lower left to the upper right. The temperature lines are skewed and, as a result, this particular sounding diagram is referred to as a **Skew-T (temperature)** chart. Other sounding charts have the temperature lines printed vertically. While the Skew-T chart's layout may be a bit more confusing, it has some important benefits. We will not examine these benefits presently. You will have to pursue a career in meteorology to learn about them.

SOUNDING PARAMETERS

As mentioned previously, the atmospheric sounding is used extensively by forecasters to assess the potential of the atmosphere to support severe thunderstorm development. Using the lines discussed in the section on the sounding diagram, the forecaster is able to derive a number of parameters that help in making this assessment. We will examine just a few of the more important ones in this section.

Consider the sounding in Figure 10-3. If an initially unsaturated parcel of air is lifted from the surface by mechanical means, it will cool at the specified dry adiabatic rate (i.e. it will follow a dry adiabat). Coincidentally, the dew point temperature will decrease, but at a slower rate. The decrease will occur along a line of constant mixing ratio. Eventually, if the lift is able to sustain itself long enough, the parcel will cool to its dew point (i.e. reach saturation). The point at which saturation is reached is known as the **lifting condensation level (LCL)**. It is at this point that additional cooling brought about by lift to the parcel will proceed at a slower rate and along a saturated adiabat. Remember, the cooling caused by lifting the parcel is partly countered by the release of latent heat as water vapor condenses.

A forecaster will make his/her first assessment of thunderstorm potential at the LCL. Essentially, he/she will check to see if the temperature of the parcel is cooler (to the left of) than the actual temperature at that height. If it is, then development is not likely, since the layer is stable and upward vertical motion is inhibited. Additional lift must be exerted on the parcel to overcome the negative energy in the layer.

The forecaster can trace the parcel along its saturated adiabat to the point at which it again intersects the sounding. This point is known as the **level of free convection (LFC)** and represents that point on the sounding at which additional movement of the parcel upward will make it warmer than the actual temperature. You will remember that this is an unstable condition and is conducive to cloud and subsequent thunderstorm development.

We must keep in mind that the parcel is still saturated as it continues to move upward, now on its own buoyancy, and therefore follows a saturated adiabat. Eventually, the parcel will again intersect the sounding. Under extremely unstable conditions, this level, referred to as the **equilibrium level (EL)**, may be very high (40,000 feet or higher). Above the EL, the parcel temperature again becomes cooler than the sounding and starts to lose its buoyancy or energy for upward movement. The parcel, of course, does not cease upward movement immediately, but gradually loses its momentum. So, while the EL may be at 45,000 feet, the thunderstorm cloud itself can extend much higher (perhaps to 55,000 feet) as it expends its positive energy.

Speaking of positive energy, the area between the LFC and EL is referred to as the **positive area** and is indicative of the atmosphere's potential for supporting strong updrafts inside a thunderstorm. The larger the positive area, the more unstable the atmosphere, and the greater the potential for strong updrafts. Forecasters are able to quantify this potential by deriving a **stability index**. We will discuss two such indices in this section.

Figure 10-3 shows how forecasters compute an index known as the **lifted index (LI)**. Typically, this index is computed at the 500 mb level. First, a parcel is lifted along a dry adiabat to its lifted condensation level, where the parcel becomes saturated. Second, the parcel is lifted along a saturated adiabat to 500 mb. Third, the parcel temperature is subtracted from the actual temperature of the atmosphere. This result is the LI. Negative LI's represent instability at that level, with lower negative values indicative of increasing instability (see Figure 10-4).

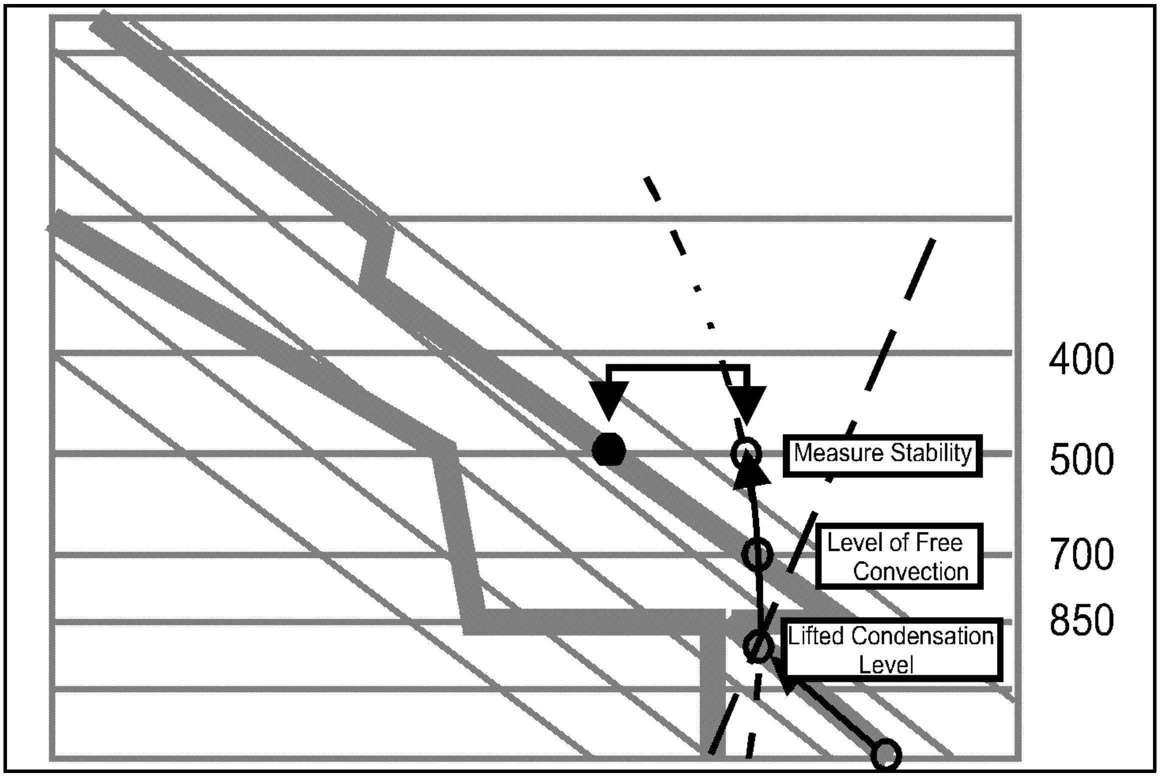

Figure 10-3: Sounding parameters. See the text for an explanation of each.

In our example the parcel temperature at 500 mb is -10 degrees Celsius (C). When compared with that of the atmosphere at the same level (-17 degrees C), we see that the resultant LI is -7, which indicates that the atmosphere is unstable at that level. A value this low is considered very unstable and certainly would gain the attention of the severe thunderstorm forecaster.

Another measure of instability and therefore storm potential that a severe weather forecaster utilizes is what is known as **Convective Available Potential Energy (CAPE)**. Don't let the complexity of the term discourage you. Its concept is really quite simple to understand physically. CAPE is essentially a quantitative measure of the amount of energy, also referred to as **positive area**, in the region between the LFC and EL. The larger the positive area, the greater the amount of CAPE. For the purposes of assessing storm potential, forecasters begin to take note of CAPE values above **1500** $\mathbf{m^2s^{-2}}$. Values above **2000** $\mathbf{m^2s^{-2}}$ mark the threshold of severe thunderstorm potential.

Meteorologists have derived a similar measure to assess the amount of negative energy in the sounding. The parameter is referred to as **convective inhibition (CIN)**. Stated in physical terms, CIN represents the amount of energy needed to overcome stability in order that instability can be released and storms can develop. In other words, CIN is a measure of how strong the cap is in the vicinity of the sounding.

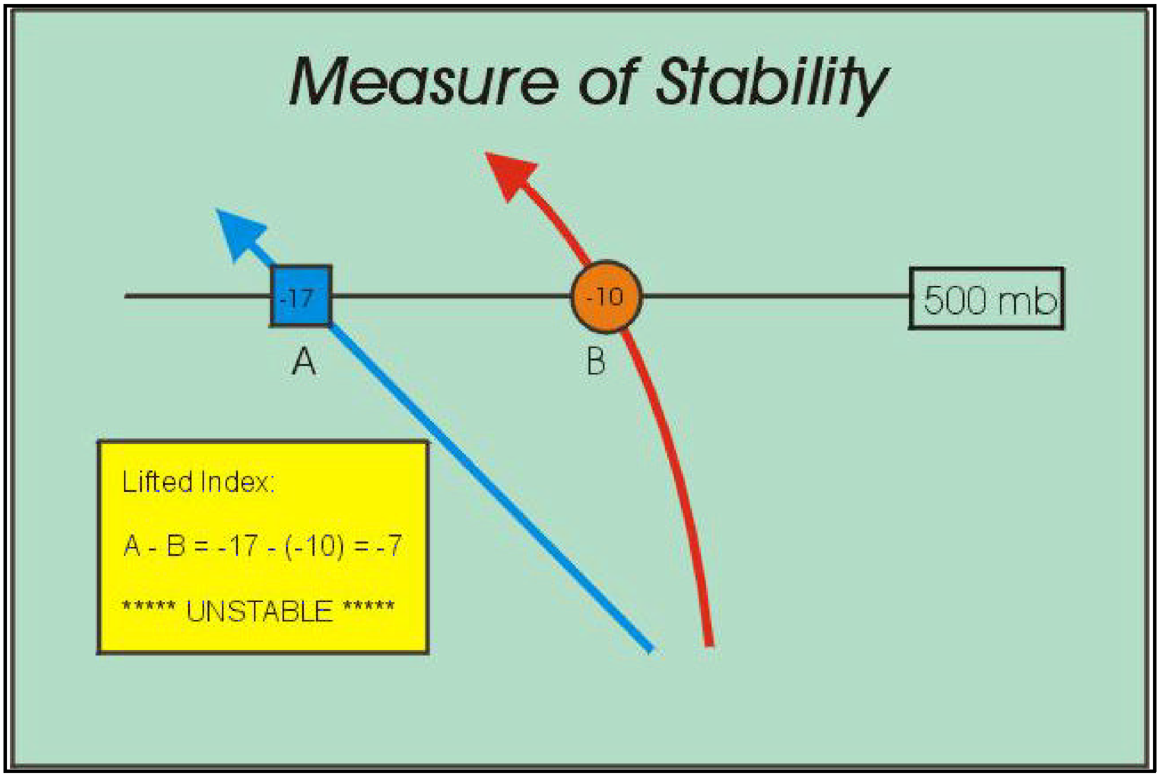

Figure 10-4: Computing the lifted index (LI). The computation procedure is explained in the text.

SOUNDING PARAMETERS GUIDE

Note: The values listed here are rough estimates based on observations of past severe weather outbreaks. There may be some events which do not perfectly fit all of these parameters.

LIFTED INDEX
LI above zero - atmosphere is stable
LI between 0 and -3 - weak instability
LI between -3 and -6 - moderate instability
LI less than -6 - strong instability

CAPE
CAPE less than 1000 - weak instability
CAPE between 1000 and 1500 - moderate instability
CAPE between 1500 and 2500 - strong instability
CAPE greater than 2500 - extreme instability

LOW-LEVEL MOISTURE (SURFACE TO 850 MB)
Less than 10 g/kg mixing ratio - probably not enough for severe storms
10-15 g/kg mixing ratio - optimal for severe thunderstorms
Greater than 15 g/kg mixing ratio - flooding threat, some severe weather

MID-LEVEL DRY LAYER (700 TO 500 MB)
Dew point depression 20 degrees or greater - optimal for severe storms
Dew point depression 10-20 degrees - sufficient for severe storms
Dew point depression less than 10 degrees - flooding threat, isolated severe weather

LOW-LEVEL JET (850 MB)
Wind speed above 40 knots - strong low-level jet
Wind speed 25-40 knots - moderate low-level jet
Wind speed below 25 knots - weak low-level jet

MID-LEVEL WINDS (700 TO 500 MB)
Wind speed above 50 knots - strong mid-level winds
Wind speed 30-50 knots - moderate mid-level winds
Wind speed below 30 knots - weak mid-level winds

UPPER-LEVEL WINDS (300 TO 200 MB)
Wind speed above 100 knots - strong upper-level winds
Wind speed 50-100 knots - moderate upper-level winds
Wind speed below 50 knots - weak upper-level winds

VEERING LOW-LEVEL WINDS (SURFACE TO 700 MB)
Wind direction turns clockwise more than 90 degrees - strong veering
Wind direction veers 30-90 degrees - moderate veering
Wind direction veers less than 30 degrees - weak veering